International Journal of Offshore and Polar Engineering (ISSN 1053-5381)
Copyright © by The International Society of Offshore and Polar Engineers
Vol. 21, No. 4, December 2011, pp. 330–336

http://www.isope.org/publications

Reliability Index Update for Driven Piles Based on Bayesian Theory Using Pile Load Test Results

Jae Hyun Park and Dongwook Kim
Korea Institute of Construction Technology, Goyang, Korea

Choong-Ki Chung
Department of Civil and Environmental Engineering, Seoul National University, Seoul, Korea

In a conventional reliability analysis, only results of pile load tests conducted to failures are counted in the uncertainty assessment regarding the bearing capacity of driven piles, and the non-failed pile load test results are not reflected in the reliability index calculation. In this paper, an analytical method is used to update the distribution of the measured-to-predicted pile capacity of a driven pile using likelihood, which reflects whether a pile has failed or not, by implementing the Bayesian theory. Reliability analyses were performed based on the updated distributions of the measured-to-predicted pile capacities using the 1st-order reliability method (FORM). It is noted that pile load test results—that is, the number of failures from the number of total pile tests—can contribute to the reliability update of a driven pile.

INTRODUCTION

In recent years, geotechnical design practice has been gradually challenged to replace the existing allowable strength design (ASD) with the limit state design (LSD). In Europe, the factored strength design (FSD) method has been established and used for a long time, and other countries, including the USA and Canada, are gradually implementing load and resistance factor design (LRFD) for various geotechnical structures. The resistance factor is generally determined based on the results of reliability-based calibration and engineering judgement. Reliability analysis calculates a reliability index that is closely related to a system's probability of failure. The reliability index is calculated from distributions (bias factors, coefficients of variation, and distribution types) of load and resistance. In this paper, for a given load distribution (or a given measured-to-predicted load distribution with a fixed factor of safety), we examined the change of the reliability index with updates of the distribution of measured-to-predicted pile capacity ($R_{M/P}$) based on the Bayesian theory. However, this paper does not consider the effect of engineering judgement on resistance factor calibrations.

The results of pile load tests conducted to failure were collected (Barker et al., 1991; Whitiam et al., 1998; Paikowsky, 2004; Allen, 2005; Yoon et al., 2008) and used in the constructions of $R_{M/P}$ distributions. It is difficult to collect a sufficient number of pile load test results conducted to failure because most static load tests, which generally check if a pile can resist up to twice its design load, are not loaded to failure. Kwak et al. (2007) collected 2,227 static load test results. Out of this large number, only 57 were results from tests conducted to failure. The distribution of $R_{M/P}$ was constructed based on these 57 pile load test results. The collection of reliable load test data is the most important task for a successful reliability analysis.

Received August 19, 2010; revised manuscript received by the editors April 15, 2011. The original version (prior to the final revised manuscript) was presented at the 20th Offshore and Polar Engineering Conference (ISOPE-2010), Beijing, June 20–25, 2010.

KEY WORDS: Axially loaded driven pile, proof pile load test, Bayesian update, reliability analysis, 1st-order reliability method.

The main purpose of this paper is:

- to update the prior (or existing) distribution of $R_{M/P}$ (constructed based on pile load tests loaded to failure) based on the Bayesian approach by adding new $R_{M/P}$ data (results of static pile load tests not conducted to failure) from pile load tests, and
- to calculate the reliability index using the updated distribution of $R_{M/P}$.

The reliability of an axially loaded driven pile (made of steel) can be revised with the updated distributions of $R_{M/P}$ following the methods used in this paper. Reliability analyses were performed using FORM, the 1st-order reliability method introduced by Rackwitz and Fiessler (1978). As this paper considers only the ultimate limit state, the issues related to the serviceability limit state or fatigue limit state are not included.

BAYESIAN THEORY IMPLEMENTATION

Update Procedure of $R_{M/P}$ Distribution Using Bayesian Theory

The Bayesian approach may play an important role in the solution of engineering problems, if data available for reliability analyses are limited. Inherently, problem variables possess variability, so they are not considered to be deterministic values. The problem variables are represented as distributions reflecting their own uncertainties. The Bayesian updating technique enables a better (or more accurate) estimation of problem variables by adding new information regarding the problem variables to their existing information. Basically, the prior distributions of the variables are updated using the Bayesian theory to new distributions that are closer to the realistic distributions.

Suppose that we have a known prior probability density distribution $P_X(x)$ of X and the marginal probability density function $P_Y(y)$ of Y. Then, the posterior probability density probability $P_X(x \mid Y = y)$ of X given that Y is equal to y is (Ang and Tang, 1975; Papoulis, 1984):

$$P_X(x \mid Y = y) = \frac{P_{X,Y}(x, y)}{P_Y(y)} = \frac{P_Y(y \mid X = x)P_X(x)}{\int_{-\infty}^{\infty} P_Y(y \mid X = \xi)P_X(\xi)d\xi} \qquad (1)$$

where $P_{X,Y}(x, y)$ is the joint density function of X and Y, and $P_Y(y \mid X = x)$ is the likelihood function of Y given that $X = x$.